

METEOROID/SPACE DEBRIS IMPACTS ON MSFC LDEF EXPERIMENTS

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SUMMARY

This paper presents the many meteoroid and space debris impacts found on A0171, A0034, S1005 and other MSFC experiments. In addition to those impacts found by the meteoroid and debris special investigative group at KSC, numerous impacts less than 0.5 mm were found and photographed. The flux and size distribution of impacts will be presented as well as EDS analysis of impact residue. Emphasis will be on morphology of impacts in the various materials, including graphite/epoxy composites, polymeric materials, optical coatings, thin films, and solar cells.

INTRODUCTION

The meteoroid and debris special investigative group noted over 34,000 impacts on the LDEF surfaces. Due to time constraints, only about 6000 of these were optically recorded. The general guidelines for photography were 0.50 mm or greater crater diameter in any material, 0.25 mm or greater penetration in any material, and any impact crater or penetration in an unusual material.

For each experiment, photographs and optical disk recordings were taken before and after sample de-integration at MSFC. Spall, impact particle residue, and secondary impact debris, if any, were photographed. The photographs were then archived with a description of the impacted material and location, crater diameter, magnification, and any comments. The optical disk recordings also have this information stored in each file.

RESULTS

A graph of the number of impacts versus the size of impact craters shows an approximate logarithmic curve, as expected. While this is a good approximation, Figure 1 should not be directly compared to the meteoroid/debris environment model, which charts the impact fluence versus the impact particle size. The particle size versus the size of crater formed varies according to material properties of both the impact particle and the impacted material.

Meteoroid and Debris Impact Features Documented on the Long Duration Exposure Facility, JSC #24608, hereafter referred to as the Meteoroid and Debris Impact Catalog, has listed for each part of the LDEF the number of impacts found and the number of those impacts photographed. The following data from each MSFC experiment are the results of the photographic scans both at Kennedy Space Center and Marshall Space Flight Center.

A0171 - Solar Array Materials Passive LDEF Experiment (SAMPLE)

The Meteoroid and Debris Impact Catalog notes that 327 features were found on tray A08, including the tray clamps, shims, and bolts. Thirty-six of the impacts on the experiment tray itself were recorded on optical disk. Unfortunately, the LeRC, GSFC, and JPL sub-trays of this experiment were returned to the co-investigators before a more detailed scan could take place. Paul Stella/JPL has identified 157 impacts on one solar cell sub-plate, with seven being >0.5 mm. At MSFC, an additional fifty-four impacts have been identified and photographed on the main experiment tray, with special emphasis on the graphite/epoxy tensile samples. Meteoroid and debris impacts may have some effect on the mechanical testing of these samples. However, some small impacts from early in the mission may have been eroded away by atomic oxygen erosion.

Generally, few material properties have been determined that would be directly affected by meteoroid and debris impacts. Solar cells with debris impacts and cracked cover slips {Figure 2} provide maximum power output similar to those not impacted. Interconnect tabs were penetrated, but a negligible amount of material was removed. Impacts and penetrations did not interfere with the mechanical peel tests of thermal control tape on fiberglass/epoxy substrates. However, impacts have interfered with optical property measurements. For example, the 1" dia. Tiodize K-17 sample from Plate IV has a relatively small (0.55 mm) crater with a large (4.1 x 3.0 mm) spall zone. {Figure 3}

Some of A0171's samples have had EDS analysis. While this is not as sensitive as SIMS analysis, it does provide some data on impactor residue and contamination. Titanium, probably from white paint, and aluminum have been found in impact craters.

A0171 had one of the more interesting impacts of the MSFC trays. Shown in Figure 4, the aluminum tray has been hit by a meteoroid or debris particle, spraying debris onto the nearby polymeric sample. Analysis is underway to correlate the crater diameter and debris cone angle to the velocity, mass, and angle of impact of the particle.

S0069 - Thermal Control Surfaces Experiment (TCSE)

The Meteoroid and Debris Impact Catalog notes that 582 features were found on tray A09. Thirty-four of these impacts on the experiment tray were optically recorded. At time of publication, this tray has not been fully scanned for impacts. Analysis has been concentrated on the complete penetration of the 0.063" thick aluminum plate. This plate is made of aluminum alloy 6061-T6 and is comparable to the current bumper design for Space Station

Freedom. There was no apparent damage to the underlying structure, indicating a full break-up of the impactor. Several of the paint samples have been impacted, but the atomic oxygen erosion and UV degradation seem to have had a far greater effect on the material properties.

S1005 - Transverse Flat-Plate Heat Pipe Experiment

The Meteoroid and Debris Impact Catalog notes that tray B10 had 414 impacts. Fifty-six of these impacts on the experiment tray were recorded on optical disk. The SIG team found thirty-one impacts on the aluminum tray flanges. A photographic scan at MSFC found ten additional impact craters on the flanges and photographed another ninety-two impacts on the heat pipes and beta cloth blankets.

The heat pipes were covered with 5 mil silver/Teflon. Impacts into this material were typical, with the darkened rings around the impact area and delamination of Teflon. {Figure 5} There were also craters through the silver/Teflon into the aluminum of the heat pipes. The diameters of these secondary craters have been noted in the photographic record as well.

In between the heat pipes were thermal blankets consisting of beta cloth and multi-layer insulation. Penetrations through the beta cloth resulted in typical secondary debris penetrations and melting of the aluminized Mylar and Dacron netting of the MLI. One particle penetrated the beta cloth layer and five layers each of the Mylar/Dacron netting. Performance loss in the thermal blankets is currently being analyzed.

A0034 - Atomic Oxygen Stimulated Outgassing and A0114 - Interaction of Atomic Oxygen with Solid Surfaces at Orbital Altitudes

The Meteoroid and Debris Impact Catalog notes that 83 and 508 impacts were found on the entire C03 tray and C09 tray, respectively. A0034 and A0114 each occupied only one-sixth of these trays. No impacts were optically recorded on the trailing edge sub-trays. At KSC, eleven and eight impacts were noted on the ram direction A0034 sub-tray and the A0114 sub-tray, respectively.

The MSFC photographic scans for A0034 have found forty-two impacts on the leading edge sub-tray and four impacts on the trailing edge sub-tray. This agrees with the approximate ratio of hits for leading edge versus trailing edge of 10:1. Only one impact, measuring 0.20 mm, was found on a UV window sample. {Figure 6} Optical property tests were performed in an unaffected area. The remaining impacts were found on the cover plates.

At the time of publication, impact scans are incomplete for A0114. However, four impacts have been found in sample materials. Two impacts were found on a carbon sample with 400 Å of gold, one was found in a solid fused silica sample, and one was found in a quartz sample with 5000 Å of silver. These impacts were typical of those found in glassy materials, with large spall zones and cracking.

Continuing Analysis

There are other experiment trays with MSFC co-investigators, such as A0172 (Effects of Solar Radiation on Glasses) and M0002 (Trapped-Proton Energy Spectrum Determination), but these were located on the trailing edge or the earth end, with very few impacts.

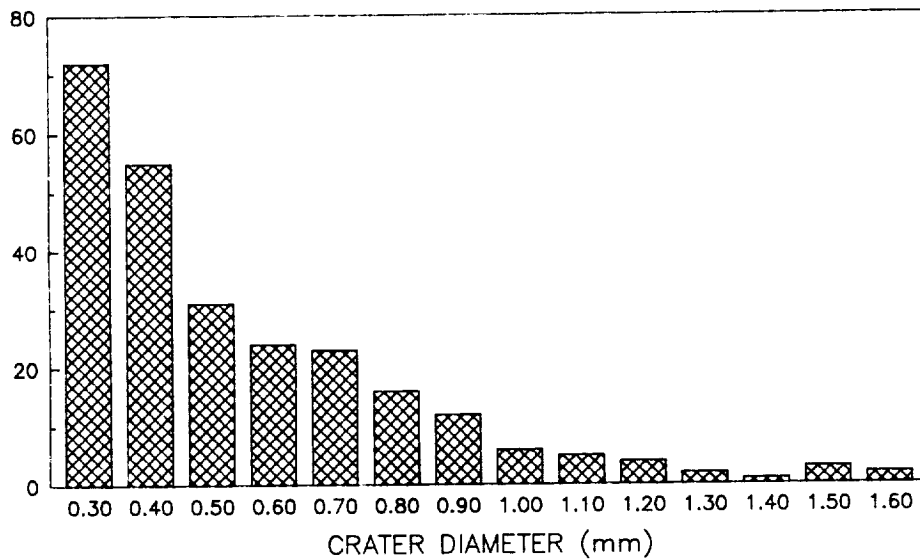
With the same stereo microscope system used at KSC during LDEF de-integration, the experiments are being more fully scanned for impacts as time permits in the laboratory. The stereo microscope has sufficient magnification for ~0.20 mm diameter and larger impact craters. Currently, smaller impacts are being photographed using a low-power stand microscope, but this survey has not been completed. Also, some of the smaller impacts have been photographed using a scanning electron microscope, but this is not practical for the thin films and polymeric samples.

CONCLUSION

For the leading edge trays, atomic oxygen erosion and ultraviolet degradation seem to have had a much greater effect on material properties than meteoroid and debris impacts. The optical property changes caused by meteoroid and debris impacts are only in small areas around the impact craters. Mass loss due to impacts is negligible. Maximum power output in solar cells is comparable in both impacted and non-impacted solar cells. However, impacts' effect on mechanical properties has yet to be determined. There are valid concerns over spacecraft protection from meteoroid/debris impacts and penetrations as the amount of space debris in orbit increases with every launch. Further analysis of the impact flux and damage should validate current debris models as well as aid applied research in debris protection systems and impact-resistant materials.

METEOROID/DEBRIS IMPACTS ON MSFC EXPERIMENTS LEADING EDGE TRAYS

NUMBER FOUND ON MSFC TRAYS



TRAYS A08, B10, C09

EXPERIMENTS A0171, S1005, A0034

FIGURE 1

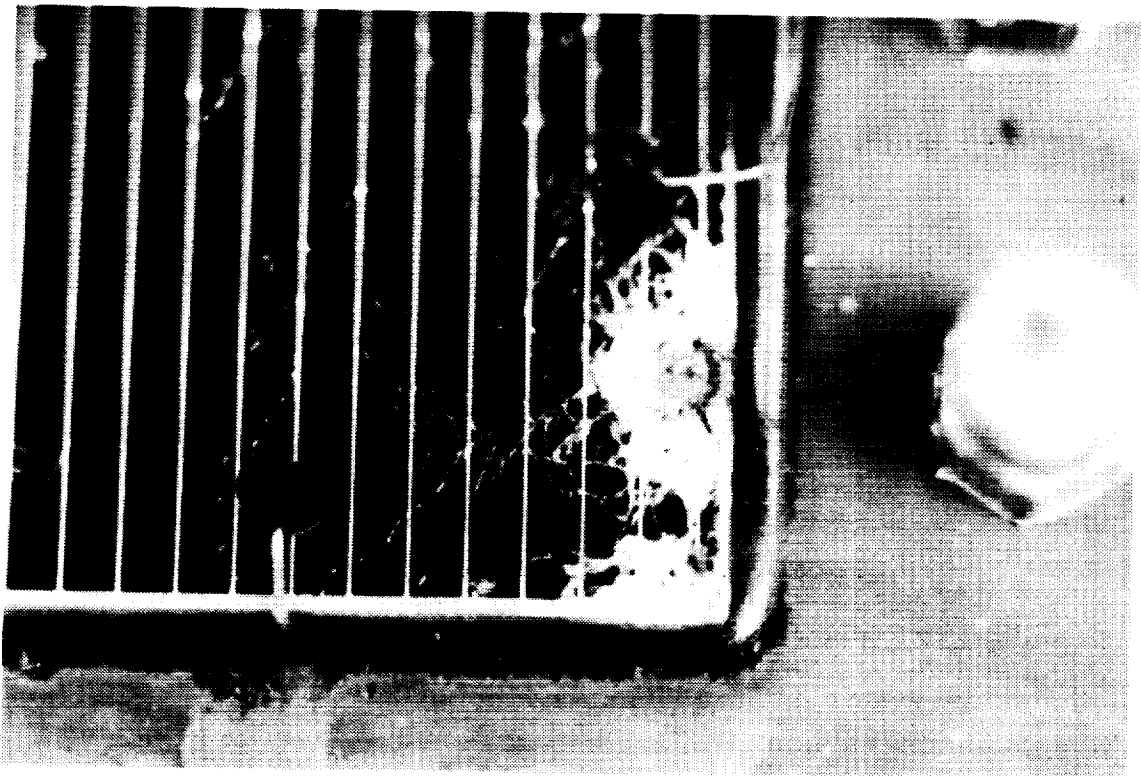


Figure 2. Solar cell, ~2 mm dia. impact crater, ~5 mm dia. fracture zone

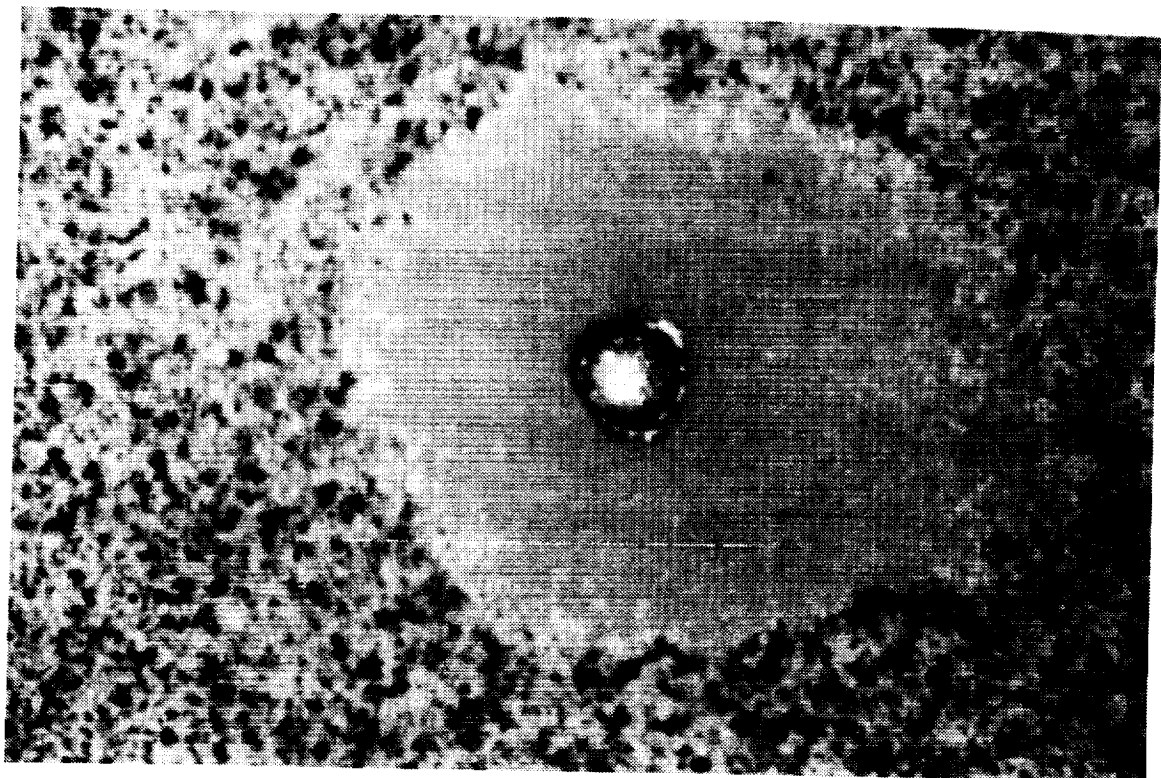


Figure 3. Tiodize K-17 on titanium, 0.55 mm dia. impact crater, 4.1 x 3.0 mm spall zone

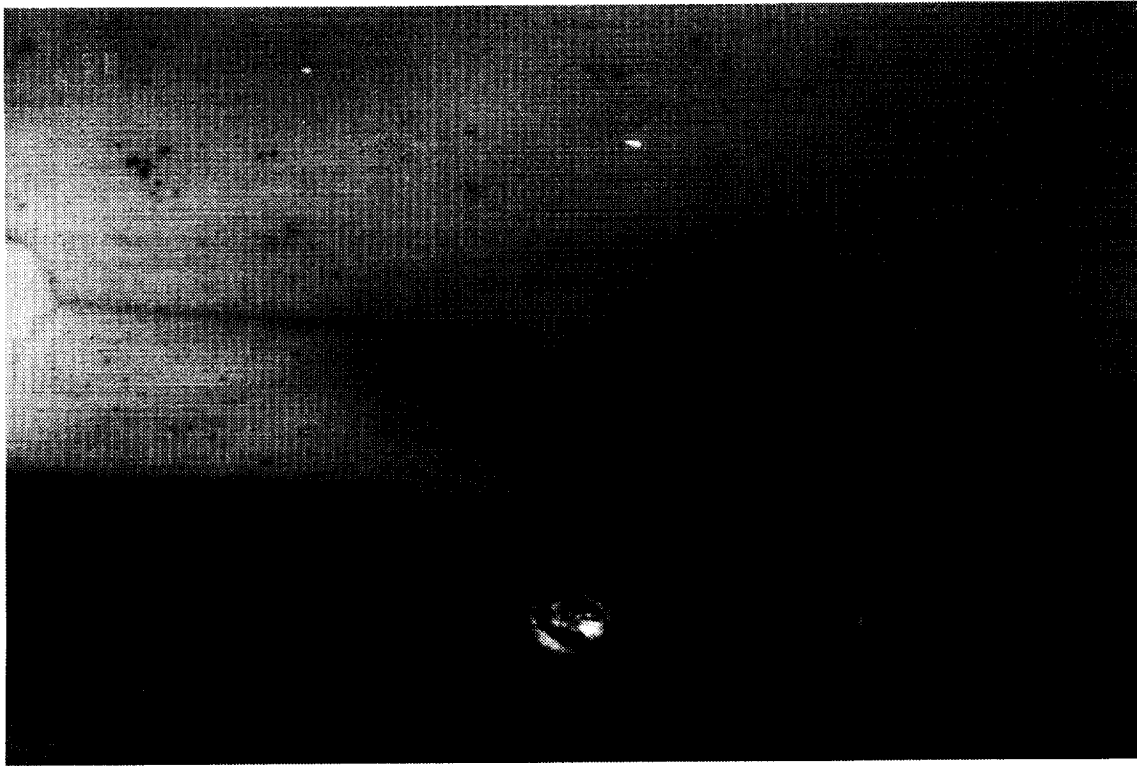


Figure 4. Aluminum tray, 0.78 mm dia. impact crater, debris spray onto RTV 511 sample

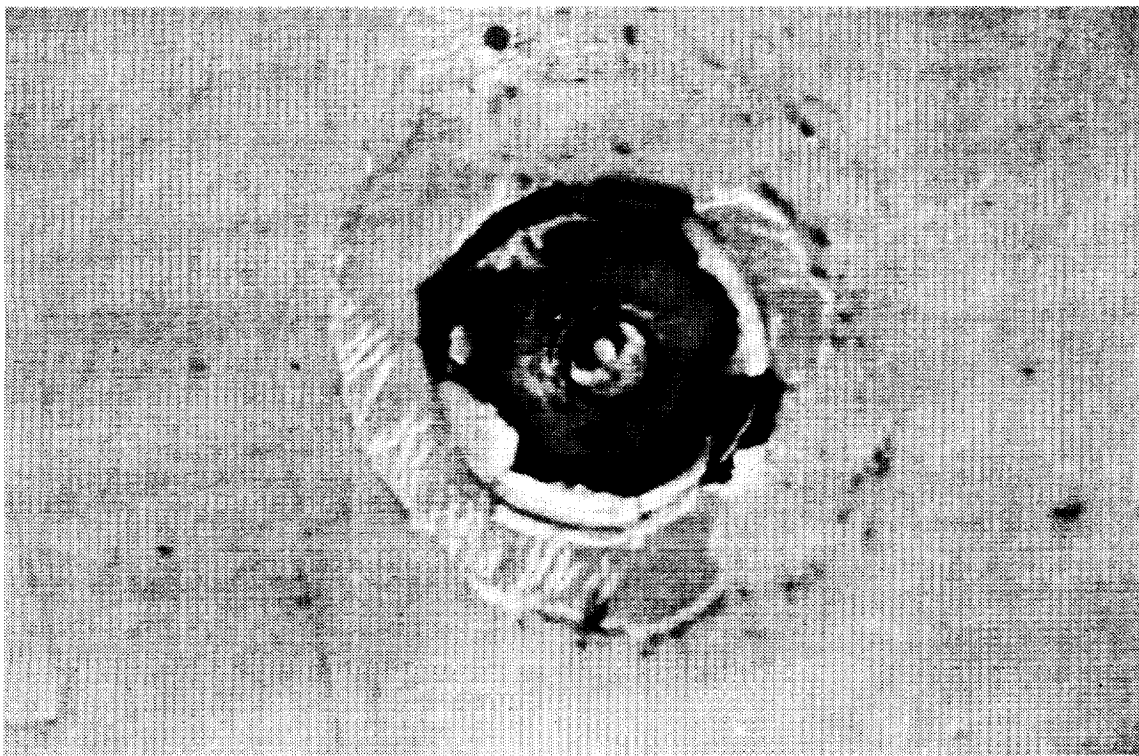


Figure 5. 5 mil Silver/Teflon on aluminum, 1.2 mm dia. crater, ~4 mm dia. dark spall ring



Figure 6. UV window, 0.20 mm dia. crater, 0.71 x 0.76 mm spall